(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number : **0 628 415 A2**

(12) EUROPEAN PATENT APPLICATION

(21) Application number : **94301232.8**

(22) Date of filing : **22.02.94**

(51) Int. Cl.^{5} : **B41J 2/205**, B41J 2/21

(30) Priority : **29.03.93 US 38449**

(43) Date of publication of application :
14.12.94 Bulletin 94/50

(84) Designated Contracting States :
DE FR GB IT

(71) Applicant : **Hewlett-Packard Company**
3000 Hanover Street
Palo Alto, California 94304 (US)

(72) Inventor : **Franz, Douglas L.**
1508 N.W. 136th St.
Vancouver, WA 98685 (US)
Inventor : **Allen, William J.**
4518 SW Illinois St.
Portland, OR 97221-28481773 (US)
Inventor : **Torgerson, Joseph M.**
24901 Hidden Valley Road
Philomath, OR 97370 (US)

(74) Representative : **Colgan, Stephen James et al**
CARPMAELS & RANSFORD
43 Bloomsbury Square
London WC1A 2RA (GB)

(54) High fidelity print modes.

(57) In an ink jet printing system (10), improved gray scale and color resolution is achieved without modifying the printing grid resolution by reducing the ink droplet volume to a level below the unit droplet volume selected to cover a nominal printing grid location. Multiple passes of the print head are used to print an integer multiple number of the reduced-volume droplets, thereby forming effective dots with greater gray scale resolution. Multiple different droplet volumes are provided in a printing system so as to achieve enhanced resolution without a linear increase in the number of print passes. Another aspect of the invention is to reduce the ink concentration or dye load again to improve gray scale resolution without changing the printing grid. Multiple different dye load concentrations may be provided for further enhancements in resolution again without a linear increase in the number of print passes required. Finally, the invention includes printing with a reduced-volume droplet of a reduced-dye load ink, called a hifi droplet, for still further improvements in print quality, resulting in printed images approximating those produced by continuously variable color densities.

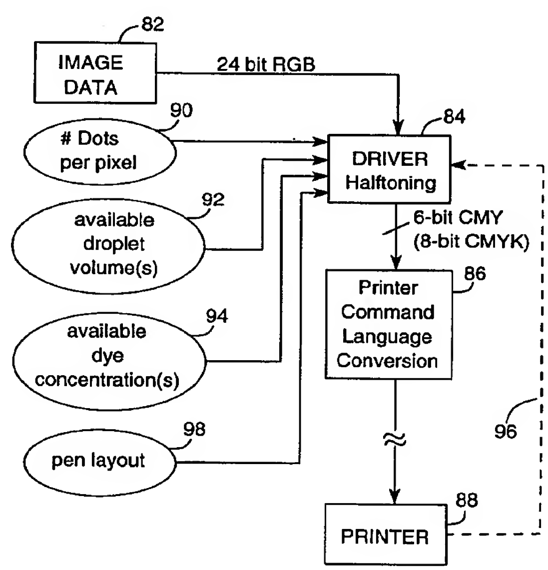

Fig. 7

EP 0 628 415 A2

BACKGROUND OF THE INVENTION

This invention generally relates to methods and apparatus for improved ink jet printing and more particularly, this invention relates to controlling the amount of ink applied to each pixel in order to achieve dramatic improvements in image quality and resolution while minimizing cost and speed penalties.

The use of ink jet printing systems has grown dramatically in recent years. This may be attributed to substantial improvements in resolution and overall print quality coupled with appreciable reductions in cost. Today's ink jet printers offer acceptable print quality for many commercial, business and household applications at costs fully an order of magnitude lower than comparable products available just a few years ago. Notwithstanding their recent success, intensive research and development efforts continue toward improving ink jet print quality. In general, print quality still falls short of that produced by more expensive technologies such as photography and offset or gravure printing. The challenge remains to further improve print quality in ink jet printing systems without increasing their cost. Efforts toward achieving this goal are limited due to the fundamental fact that the drop on demand method and most of the continuous ink jet methods are essentially binary: at each picture element (pixel) of the paper (or other output media) they must place a droplet of ink or no ink at all. This sharply limits gray scale resolution.

Color ink jet printers typically use only three or four colors of ink (magenta, yellow, cyan and optionally black). Consequently, only a very limited range of color shades can be printed by different combinations of these colors in each pixel. The range of colors that can be so formed, i.e. the color resolution, is strictly limited because more than two or three drops of ink together form a volume that is excessive and therefore tends to bleed and mottle the paper. This limitation has been circumvented somewhat by the so-called dither techniques, in which the picture is divided into a large number of square matrices, each matrix containing a certain number of pixels, such as 4x4 or 8x8 pixels. Different shades of color can be obtained by filling different numbers of pixels in each matrix with ink. Hence, using a 4x4 matrix 16 different shades of color and white (no color) can be generated, while an 8x8 matrix allows the rendition of 64 shades of color in addition to white. Dithering thus reduces the effective spacial resolution for all colors other than the basic system colors. The **basic system colors** of a given system are those colors that can be printed within a single grid location. Moreover, despite sophisticated dithering and digital halftoning techniques, the relatively large size of the ink drops generally lead to coarse images, such that the eye perceives an apparent graininess in the print.

Printed image quality would be improved dramatically if the color density in each pixel could be varied continuously. It can be varied nearly continuously by use of very small pixels, so that they cannot be resolved by the unaided human eye at normal viewing distances. So for example, an image formed on a grid of 100 pixels to the millimeter will have the same appearance when viewed by the unaided eye as a truly continuous tone picture typified by photographic color print. The problem is to achieve this kind of improved resolution at low cost.

It is known in the art to form each printed dot with at least two droplets of the same color ink, each droplet being ejected from a different nozzle, in order to reduce the effects of nozzles which may be blocked or partially inoperative. The second droplets of ink are applied during a second or return pass of the printhead. A technique of this type is disclosed in U.S. Patent No. 4,963,882. This "double dot" technique does not improve resolution.

U.S. Patent No. 4,494,128 to Vaught entitled "Gray Scale Printing with Ink Jets" discloses valving apparatus in a thermal ink jet system for mixing vehicle (dilutant) with the ink during the actual jet printing process to produce variation in visual print density (gray scale). Adapting such as system for color mixing in the transducer chamber is suggested. Such techniques are difficult to implement in practice.

U.S. Patent No. 4,620,196 to Hertz et al. describes a method and apparatus for high resolution ink jet printing. The Hertz patent is directed to a rather complex and therefore expensive system. It describes an ink jet printing system of the type in which a continuous stream of very small droplets of ink is emitted at a very high, fixed frequency, such as one million droplets per second. An electric signal called the "print pulse" controls an electrode surrounding the point of drop formation, so that the drops generated by the continuous jet are either charged or uncharged. When these drops subsequently travel through an electric field, the charged drops are deflected into a catcher while the uncharged drops travel undeflected onto the recording paper. According to the Hertz patent, the amount of ink applied in each pixel is controlled by varying the number of droplets applied to the pixel. The number of droplets is controlled by the time duration or pulse width of the control signal, since droplets are firing at a constant rate. This technique provides high resolution. For example, the patent suggests that 0-30 drops of ink might be applied to a given pixel, resulting in nearly continuous resolution to control color density.

As stated in the Hertz patent itself, "while the principal of the invention appears to be and in fact is relatively simple, it is actually very difficult to put into practice." The Hertz et al. patent discloses several problems associated with the printing system described above. For example, the diameter of the drops has to be very small

and the drop generation rate must be generally high and essentially constant. Also, because of the high air resistance encountered by the very small drops, not only individual drops but also groups of drops tend to merge on their way to the paper which gives rise to an appreciable graininess. Accordingly, the jet diameter must be small and its velocity high to ensure a high drop generation rate. Ultrasonic stimulation of the drop formation process of the jet is essential to ensure high and constant drop generation rate and to control drop diameter. There must an electrical apparatus for slightly charging the drops which are meant to reach the paper, with like charges thereby causing a repulsive force between them to counteract the merging tendencies of the drops. These and other challenges and added complexities lead to a very high cost apparatus. Accordingly, the need remains for producing high quality output from a color ink jet printing system at low cost.

U.S. Patent No. 4,499,479 to Chee-Shuen Lee et al. describes gray scale printing with a cylindrical piezoelectric transducer printing head arranged for varying ink drop volume in real time. Specifically, the transducer is divided into separately actuable sections. Drive signals selectively actuate one or more of the sections so as to form an internal pressure wave in response to print data to form an ink drop of a desired volume. Amplitude of the drive signals may be varied to further control ink drop volume. Pulse width of the drive signals additionally may be varied for further refinement. Control means for providing such drive signals, however, is relatively complex. Moreover, this strategy of segmenting the transducer is not applicable to thermal ink jet printing.

U.S. Patent No. 4,617,580 to Miyakawa discloses an ink jet printer which includes a detector to determine whether the printing medium is paper or overhead transparency. In the latter case, the printer applies a plurality of ink droplets onto the usual one pixel area, slightly offsetting each of the droplets horizontally and/or vertically from each other, in order to improve coverage of the media as is necessary for ink jet printing on overhead transparencies. According to that patent, the ink dots may be vertically shifted by providing a fine feed pitch of the recording paper and the ink dots may be horizontally shifted by shifting the delay times for the ejection timings, or by providing a fine horizontal ejection pitch. The droplets are shifted slightly in order to better cover the pixel area because of the overhead transparency having a low diffusion property, which leads to a small color dot size for a given volume ink droplet. Providing finer paper feed pitch (vertical) and/or finer horizontal resolution (i.e. carriage positioning), however, requires substantial improvements in the corresponding mechanical assemblies and increases cost dramatically.

SUMMARY OF THE INVENTION

The present invention includes methods and apparatus for practicing the methods of improving gray scale and color resolution in thermal ink jet printing systems without requiring increased printing grid resolution. The present invention thus substantially retains known carriage and paper handling electro-mechanical assemblies. The invention provides for improved resolution within the context of a predetermined pixel grid by better controlling ink droplet total volume and/or ink dye concentration.

According to a first aspect of the invention, a nominal or "unit volume" of ink is defined as a volume of ink selected for covering approximately one pixel location on a given printing medium. In other words, the unit volume is the usual volume of a single droplet of ink expelled by a nozzle on the pen. To improve print quality, ink droplet volume is reduced below the unit volume, and multiple printing passes are used to permit depositing more than one such reduced-volume ink droplet on each pixel location. A unit volume of ink therefore may be formed (or approximated) by depositing at least two reduced-volume ink droplets on the same pixel location.

In one example, the reduced volume is equal to one-half the unit volume. This has the advantage of increasing resolution of print density by providing a choice of three levels, i.e., zero, one-half volume or unit volume rather than the usual binary mode. The incremental cost of implementing the higher color (or gray scale) resolution is modest because the printing grid resolution, e.g. 300 DPI, is retained. Thus no modification to the printer mechanics and drive means that define the printing grid is necessary to use the invention.

A second aspect of the invention is to provide at least two different droplet volumes in a printing system. These may implemented in a single print cartridge or by using multiple print cartridges. One example is a print cartridge having half of its nozzles arranged to deliver 1/3 unit volume droplets and the other half arranged to deliver 2/3 unit volume droplets. Where both droplet volumes are available on the same horizontal line (an "in-line pen layout" -- see FIG. 3A), a single pass of the printhead yields any one of four possible total ink volumes: 0, 1/3, 2/3 or 3/3 (one) unit volume of ink at each grid location, thereby increasing resolution. A second pass of the same printhead allows a total of 4/3, 5/3 or 6/3 (two) units of ink at each grid location, for a total of seven possible levels. Using an offset pen layout (see FIG. 3B), the same seven levels are available over four passes. This principle is extendable in that more variations of droplet volume and more passes could allow for even smaller dots and larger numbers of dots per printed unit area to achieve even greater resolution.

A third aspect of the invention is to improve print quality by varying ink colorant concentration, also called "dye load". Dye load is the relative amount of dye or colorant in a printing solution, as distinguished from the

carrier or solvent portion of the ink which evaporates soon after the ink is applied to the medium. The dye load of an ink affects the printed dot color density. Reduced dye load in the ink thus can be used to improve spacial resolution and increase the number of basic system colors.

A fourth aspect of the invention is a method of printing that utilizes multiple dye loads provided in a single pen. For example, a three-chamber pen could be used to provide three different dye loads of a particular color ink. Three dye concentrations and two passes provides for 27 gray scale levels. In a color system, three dye concentrations may be provided for each color. In a CYM system, for example, this arrangement makes possible 19,683 dot combinations (27 cyan) x (27 magenta) x (27 yellow), thereby providing 19,683 basic system colors.

A fifth aspect of the present invention is a combination of the reduced ink volume and reduced dye load techniques. These two variables may be controlled independently to achieve substantial improvements in resolution, again without changing the drive mechanics, hardware and software that define the printing grid. The benefits of the invention of course apply to any printer grid size.

The foregoing and other objects, features and advantages of the invention will become more readily apparent from the following detailed description of a preferred embodiment which proceeds with reference to the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a known ink jet printer mechanism.

FIG. 2 illustrates a known arrangement of nozzles on a thermal ink jet pen.

FIG. 3A illustrates an in-line pen layout for providing multiple different ink droplet volumes in an ink jet print cartridge.

FIG. 3B illustrates an offset pen layout for providing multiple different ink droplet volumes in an ink jet print cartridge.

FIG. 4 illustrates use of reduced-volume ink droplets in color printing.

FIG. 5 illustrates use of multiple different reduced-volume ink droplets.

FIG. 6 is a perspective view of an ink jet printer mechanism having multiple pens disposed therein for providing multiple different ink droplet volumes and/or multiple different ink dye concentrations.

FIG. 7 is a flow diagram illustrating one implementation of the invention in an ink jet printing system.

The following Tables also form part of this specification:

TABLE 1. Basic System Colors for a Three-Color System, Two Passes.

TABLE 2. Basic System Colors for 300 DPI Color and 600 DPI Black, Two passes.

TABLE 3. Basic System Colors for Various Dye Loads and Print Passes.

TABLE 4. Examples of Hifi Droplets.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Printer Apparatus Overview

Referring to FIG.1, indicated generally at 10 is a non-continuous ink jet printing system. Ink jet printers of this type are known in the art of printing, e.g., the Hewlett-Packard Desk Jet 550C™. The salient elements of the printer include a transverse rod 12 which spans the width of the printer 10. Mounted on the transverse rod 12 is a carriage 14 which moves linearly along transverse rod 12. Not shown in FIG. 1 is a means for advancing the carriage along the transverse rod 12. However, such means are well known in the art and include stepper motors and gears. Carriage 14 is designed to receive print cartridges 16 and 18. Print cartridges 16 and 18 each contain separate reservoirs of ink. In the preferred embodiment, print cartridge 16 contains three separate color pigments (C,Y,M), and print cartridge 18 contains a fourth color pigment (K). Located on the underside of each print cartridge is a plurality of ink jet nozzles through which ink stored in the respective cartridge passes. The ability to selectively enable the nozzles to form a desired image on a print media is known in the art of ink jet printing.

Print media such as paper provided in media tray 20 is removed from the media tray 20 by typically a set of driver rollers (not shown) and advanced along axis X in a controlled manner. As the print media passes along the X-axis the carriage 14 is advanced along the transverse rod 12 so as to position print cartridges 16 and 18 over the print media. When the cartridges 16 and 18 are positioned in the desired location, the appropriate nozzles on either or both cartridges are enabled. The enabled nozzles form ink droplets therein which are subsequently deposited on the print media below. The carriage 14 is then advanced further along the transverse rod 12, usually by an amount which defines the horizontal resolution of the printer, and the entire process is

repeated. Once the carriage has spanned the entire width of the print media, the print media is advanced by a predetermined amount, usually defined by the vertical resolution of the printer, and the carriage 14 retraces its path in the reverse direction along the transverse rod 12.

FIG. 2 shows one example of an arrangement of print nozzles on a prior art print cartridge 22. In this example, each nozzle is represented by a small circle. The print nozzles are arranged in six parallel vertical columns. (Vertical here meaning perpendicular to print cartridge travel.) There are sixteen nozzles in each column in this example, though the number is a matter of design choice. Each pair of columns, for example columns 24 and 26, are vertically offset from one another by one-half the distance between adjacent nozzles within a column. This provides better vertical resolution. For example, it is difficult to implement ink jet nozzles on 1/300th inch spacing within a single column. 300 dpi printing can be achieved by providing two parallel columns of nozzles such as columns 24, 26 for each color ink and spacing the nozzles 1/150th of an inch apart vertically within each column. By offsetting the columns by 1/150th of an inch, 300 dot per inch vertical resolution is available by appropriately actuating nozzles from one of the two columns as needed.

Reduced Ink Droplet Volume Printing

A dot is a single spot of ink printed on paper or other medium. Smaller dots improve print quality by making individual dots less distinguishable. For instance, smaller dots make smoother, less grainy textures in light color and tones. Increasing the number of dots in a given area allows more information to be displayed in the same area of the paper, thereby increasing the number of possible colors or gray levels. Color transitions between blended hue shifts are smoother and intermediate halftone colors are more uniform. Other benefits realized are better draft quality, better composite blacks, lighter secondary colors and increased flexibility in dye balancing.

We first define a **unit ink droplet volume** as the usual volume selected for covering approximately one pixel location on a given printing medium. To improve print quality, the ink droplet volume is reduced below the unit volume, and multiple printing passes are used to permit depositing multiple reduced-volume ink droplets on each grid or pixel location, one droplet per pass. A grid location is the finest resolution on which the printing device can place dots. For instance, a 300 dot per inch (dpi) machine prints at 1/300th- inch grid locations. According to the invention, multiple reduced-volume dots are printed at each grid location by printing a single dot each time the print cartridge passes over the location. The total number of dots printed at each location thus is less than or equal to the number of print passes. (This is not necessarily true for multiple volume printing with an in-line pen layout, discussed below.)

In one example of an embodiment of the invention, the print cartridge is modified so as to provide an ink droplet having one-half of the "unit" volume, i.e. the volume of a "normal" drop for the same resolution. As the carriage makes a first pass over the print media either no drop or a half-drop is deposited on each pixel location, depending upon the desired image. As the carriage makes a second pass over the print media, the printer again can deposit no drop or a half-drop on any particular pixel location. Thus, three distinct combinations of drops are available to each pixel location using two passes: no drops; a single drop; or two drops. In a three-color system, this strategy provides 27 dot combinations: 6 primaries, 12 secondaries and 8 composite black or near neutrals (plus white).

Referring now to FIG. 4, selected dot combinations are illustrated on a predetermined rectangular grid printing 30, consisting of a regular array of pixel areas, for example pixels 32,34. Colors are indicated by striping orientation as shown for yellow, cyan and magenta. The droplet volume, it may be observed, is significantly less than a unit volume which would substantially cover a pixel area. (More complete coverage of a pixel can be achieved with even smaller nominal dot size by shifting vertically and/or horizontally. This "phase shifting" can be effected in the pen layout or by modifying dot firing timing, but modifying the printing grid is generally not desirable.)

In FIG. 4, the four adjacent pixels that form the upper left quadrant 36 of grid 30 each contain a single dot of each color. All three colors were printed on each of two passes, for a total of six droplets. In the upper right quadrant 38, magenta and cyan dots were printed, again one dot of each color on each of two passes, for a total four droplets. The lower left quadrant 40 illustrates just one dot each of yellow and magenta inks and finally, the lower right quadrant 42 shows dots of magenta and cyan. The lower quadrants could be printed on one or two passes. FIG. 4 illustrates only a few of the many possible combinations of dots. The 27 possible combinations are listed in the following Table 1.

Table 1.

Basic System Colors for a Three-Color System, Two Passes, Reduced Volume				
Number	Cyan	Magenta	Yellow	Comment
1	0	0	2	primary yellow
2	2	0	0	primary cyan
3	0	2	0	primary magenta
4	0	0	1	primary yellow
5	1	0	0	primary cyan
6	0	1	0	primary magenta
7	1	0	2	secondary
8	2	0	2	secondary
9	2	0	1	secondary
10	0	1	2	secondary
11	0	2	2	secondary
12	0	1	2	secondary
13	2	1	0	secondary
14	2	2	0	secondary
15	1	2	0	secondary
16	1	0	1	secondary
17	0	1	1	secondary
18	1	1	0	secondary
19	1	2	1	near neutral
20	2	1	1	near neutral
21	1	1	2	near neutral
22	2	1	2	near neutral
23	2	2	1	near neutral
24	1	2	2	near neutral
25	1	1	1	composite black
26	2	2	2	composite black
27	0	0	0	white (no dots)

Note that the selected sequence of printing the various color dots results in a slight hue shift in the resulting printed image as compared to a different sequence. This effect can be taken into account to provide an even greater range of basic system colors than those described here explicitly.

Translation of computer source data (image data) to specific printer dots is performed by a printer driver, typically implemented in software. The driver software uses digital halftoning techniques to translate the image

data to the resolution of the target output device. To illustrate, the present invention may be applied to a 300 x 300 DPI cyan/yellow/magenta printing system. Digital halftoning would be used (in the printer driver) to reduce the source data from 24 bits per pixel (8 bits per color) to 6 bits per pixel. The 6-bit data contains three 2-bit components, one each for cyan, magenta and yellow. Each of the two bits controls one 1/2 unit volume droplet at a given print grid location.

Printing with multiple passes has additional advantages. It improves ink bleed control as well as hides mechanism and pen dot misplacement errors. The incremental costs of implementing this print mode is minimal since the grid resolution remains constant. The fine pitch controls for shifting dots as suggested in the Miyakawa patent are not required. There is a penalty in increased time to print a page, though in many applications multiple passes are already in use for other reasons such as the so-called "shingling" technique. Moreover, a choice of print modes may be provided under user control which would enable the user to disable the high resolution print mode in order to produce draft quality output at higher speed. The user selection is input to the driver software to control halftoning.

This principle of the invention may be extended to further reductions in ink volume, with the result of corresponding improvements in print quality. For example, 1/3 unit volume droplets may be printed over three passes. Similarly, the ink volume may be reduced to 1/4 of the unit droplet volume, and four print passes utilized. One-quarter volume droplets provides five levels of density at each grid location for each primary ink (four levels of ink plus no ink). Five levels provide 5x5x5 or 125 combinations of primary color droplets at each grid location in a three-color system. The system thus has 125 basic system colors.

Other variations may be used, such as further reducing the ink droplet volume to 1/8 the nominal value. One-eighth droplet volume provides nine density levels for each primary color, resulting in 9x9x9 or 729 possible color combinations at each grid location over nine passes (for a three color pen). In a four color (e.g. KCMY) system, a 1/8 drop volume would yield 9x729 or 6,561 basic system colors.

Print quality can be still further improved by increasing the black ink resolution in combination with the reduced-volume strategy. Since most image information is contained in the gray content, a substantial improvement in color quality can be gained for a small increase in cost using this approach. To illustrate, in a 300 DPI color system, increasing the gray resolution to 600 DPI essentially provides resolution up to a five-level gray system at each grid or pixel location. One-half unit volume color dots may be printed as above, over two passes. Black ink, however, could be printed with 0,1,2 or 4 dots in a 2 by 2 dot superpixel which fills a 300 x 300 grid location. The black droplet volume is about 1/4 of the nominal 300 DPI droplet volume. This arrangement provides four gray levels at each pixel with minimum black dot size. The available dot combinations at each pixel are summarized in the following Table 2. More than 50 of the combinations are useable.

TABLE 2.

Basic System Colors for 300 DPI Color and 600 DPI Black, Two passes, Reduced Volume.	
(a) 27 colors	(with no black)
(b) three grays	(black dots only)
(c) six dark primaries	(six primaries plus one black dot at each pixel)
(d) six darker primaries	(six primaries plus two black dots at each pixel)
(e) 12 dark secondaries	(12 secondaries plus one black dot at each pixel)
(f)12 darker secondaries	(12 secondaries plus two black dots at each pixel)

Thus, the reduced-volume print method improves color and/or gray scale print quality by implementing reducing dot size and increasing the number of dots in a given area. Importantly, improved print quality also may be achieved without a linear increase in the number of passes by providing multiple droplet volumes, described next.

Multiple Volume Printing

Another aspect of the invention is to employ multiple different droplet volumes within a single drop-on-demand printing system. Preferably, multiple different droplet volumes are implemented in a single print cartridge, although multiple cartridges may be mounted on a single carriage. Each of the available droplet volumes is predetermined. Referring now to FIG. 6, a portion of an ink jet printer is shown in perspective view. A modified

carriage 70 is mounted on a transverse rail 72. Carriage 70 is arranged to receive and transport four print cartridges 62, 64, 66 and 68. Each cartridge is arranged to provide droplets of ink of a single color, for example C,M,Y or K. Each cartridge further is arranged to provide for selection among at least two different droplet volumes of the corresponding ink on demand.

One example of a pen nozzle arrangement ("pen layout") for printing multiple ink droplet volumes is illustrated in FIG. 3A. Referring to FIG. 3A, the nozzles are arranged in three pairs of columns, one pair of columns for each color. For example, both columns 78 and 80 eject drops of cyan ink. However, the droplet volume ejected by the nozzles in column 78 is less than that of column 80. For example, column 78 nozzles may provide 1/8 unit volume droplets, and column 80 provide 3/8 volume droplets.

Variations in ink droplet volume need not necessarily be provided by altering nozzle or bore size. Appropriate modifications to the internal construction of the cartridge, and/or variation of the drive signals that control the cartridge may be used to alter droplet volume. Control of droplet volume in a thermal ink jet print head is discussed in U.S. Pat. No. 4,339,762 incorporated herein by this reference.

A printing method that employs multiple different droplet volumes allows wider control of droplet volumes without a linear increase in the number of print passes. For example, a print cartridge may be provided having half its dots at 1/3 unit volume and the other half at 2/3 unit volume. The nozzles may be arranged so that both volumes are available on the same horizontal line, thereby allowing printing either or both volumes on a single pass. We call this an in-line pen layout, illustrated in FIG. 3A. Using a pen so arranged, 0, 1/3, 2/3 or 3/3 droplet volumes may be printed at each grid location on a single pass. Alternatively, the nozzles may be arranged with the different volumes vertically offset from each other, as in FIG. 3B. We call this an offset pen layout. Other arrangements, such as diagonal layouts, are possible. Two passes of the offset layout pen provide the four ink volume levels just mentioned.

Referring now to FIG. 5, a portion of a printing grid 44 has three columns of pixels, columns 46, 50 and 54. The pixels that form column 46 each contain one dot of ink, for example dot 48, each dot having approximately 1/3 unit volume. The pixels that form column 50 also each contain one dot of ink, for example dot 52, these dots having approximately 2/3 unit volume. The pixels that form column 54 each contain two dots of ink, for example multiple dot 56. Dot 56 is formed of a 2/3 volume droplet 57 together with a 1/3 volume droplet 58. Any or all of these dots may be printed on a single pass using an in-line pen layout as described, or printed over two passes using the offset pen layout. This aspect of the invention is extendable by selecting other variants of droplet volume, and using additional passes to allow even smaller dots and larger numbers of dots per area. We have found these techniques to provide substantial improvements in print quality without changing the basic printing grid resolution.

In another example, a print cartridge has half of its nozzles arranged to deliver 1/8 unit volume ink droplets, and the other half at 3/8 unit droplet volume. In this case, two print passes (using an in-line pen layout) provide nine density levels, i.e. any one of 0, 1/8, 2/8, 3/8, 4/8, 5/8, 6/8, 7/8 and 8/8 units total ink volume at each grid location. The same resolution is achieved using four passes of the offset pen layout. Volumes exceeding the normal unit volume, i.e. 10/8 (125%) and 12/8 (150%) also are available on four passes. These may be useful, for example, when printing overhead transparencies or other media that require increased ink volume. In a color system, for example a CMY system, nine levels per pixel per color provides for (9 cyan) x (9 magenta) x (9 yellow) equals 729 dot combinations or basic system colors.

There is some latitude in which dot combinations are actually used and how data is encoded to drive the printer. For example, seven or eight of the nine possible ink volumes of the previous example may be selected as the most useful. In that case, the driver software may be arranged to provide 3-bit data per color per pixel, thereby specifying one of the selected levels.

The present invention can be applied to other scanning head printing or imaging technologies where the absolute dot size is quantisized and the effective dot size or density increases when multiple absolute dots form a larger effective dot.

Reduced Dye Load Printing

Another aspect of the invention is to improve print quality by moderating ink concentration, also called "dye load". We first define a **standard dye load** as the usual or normal dye load selected for forming a dot of acceptable size and density (and other characteristics) when a unit volume droplet of the standard dye load ink is applied to a given medium. A one-half dye load ink droplet (still unit volume) thus would provide only one-half as much dye to the paper as a dot of unit dye load ink. The reduced-dye load dot has a lower optical density than the standard dye load dot.

Reducing dye load has the advantage of increasing density resolution. For example, reducing dye load to one-half of the standard dye load provides essentially three dot sizes, i.e., zero, half dye load or standard dye

load, rather than the usual binary mode. Two passes may be necessary to print a full-density dot on a given pixel (i.e. two of the one-half dye load dots), depending on the pen layout. However, two passes are used in many ink jet printer applications for other reasons. Moreover, the incremental cost of achieving higher resolution through reduced dye load is modest because, as in the case of reduced ink droplet volume techniques, the existing printer grid resolution, e.g. 300 DPI, may be used. No modification is necessary, therefore, to standard printer mechanics and drive means that define the printing grid.

A reduced dye load method is particularly attractive because it may be implemented in many ink jet printer systems without any hardware modifications. The reduced dye ink may be provided in replaceable print cartridges, and the necessary changes in printing strategy are implemented in the dithering software. As explained above with regard to ink droplet volume, the dye load may be reduced to for example 1/2, 1/3, 1/4 etc with a corresponding increase in the number of print passes.

Multiple different dye loads may be especially advantageous. Preferably, such various dye loads are available within a single print cartridge. This strategy allows substantial increases in resolution (number of density levels) without a linear increase in the number of passes. Ink droplets of various dye concentrations can be combined in a single pixel. An example is a system having three dye loads available, and using two passes of the print head. This would allow up to two drops of each dye concentration to be delivered to each grid location. The dye loads are selected so that one medium drop is darker than two light drops, and one dark drop is darker that two medium drops.

Then 27 density levels are available on two passes. The first level is where there are no drops deposited. The second level includes only a single light drop. The third level corresponds to two light drops deposited one atop another on subsequent passes. As was stated earlier, two light drops produces a lighter drop than one medium drop of level four. Level five includes one medium drop and a light drop. Level six includes two light drops and a single medium drop. Level seven consists of two medium drops, each deposited on a separate pass of the carriage. Level eight includes two medium drops and a light drop, wherein the light drop and one of the medium drops is deposited on the first pass and the second medium drop is deposited on the second pass.

Level nine consists of two light drops and two medium drops with one light drop and one medium drop deposited on each of two successive passes. To produce levels 10-18, a single dark drop is added to levels 1-9. To produce levels 19-27, a second dark drop is added on the second pass to levels 10-18. In this manner, twenty-seven different levels of color intensity or gray-levels can be produced for each color using three die concentrations while making only two passes over the print media. In a three-color system, (27 cyan) x (27 magenta) x (27 yellow) = 19,683 dot combinations are available using this three dye load method over just two passes.

In one operative example of an embodiment of the invention, a dark drop has 100% concentration (i.e. the standard dye load), a medium drop has a 20% concentration, and a light drop has a 2% concentration. Note that this combination yields a wide dynamic range while using a minimum number of drops or passes. Specific dye loads may be optimized empirically for particular print media and environmental conditions. Varying dye load and the number of print passes provides various ranges of gray levels and color combinations. Some examples are summarized in the following Table 3:

TABLE 3.

Basic System Colors for Various Dye Loads and Print Passes.			
No. Dye Loads	**Print Passes**	**Gray Levels**	**Basic System Colors**
3	1	8	512
3	4	125	1.953 Million
2	2	9	729
2	4	25	15,625

Referring once again to FIG. 4, recall that four print cartridges 62, 64, 66 and 68 are disposed on a single carriage. Each cartridge is arranged to provide droplets of ink of a single color, for example C,M,Y or K. Previously, each cartridge was of ink of a single color, for example C,M,Y or K. Previously, each cartridge was described as providing at least two different droplet volumes of the corresponding ink on demand. Alternatively, each cartridge may be arranged to provide at least two different dye concentrations of the corresponding ink.

For example, three-chamber pens are known for providing three colors of ink. A known ink cartridge could instead be filled with three different dye concentrations of the same color ink for implementing the methods described herein. In using multiple different reduced dye loads

Hybrid Systems - Hifi Droplets

Another aspect of the present invention is to combine the reduced ink volume and reduced dye load techniques disclosed above. An example is a printing method that employs both a reduced-volume ink droplet (say 1/4 unit volume) and a reduced dye load (say 1/2 of a standard dye load). A dot formed by this printing method provides approximately 1/8 the normal dot size and density. We will call a reduced-volume droplet of reduced-dye load ink an "hifi" (high fidelity) droplet. Multiple hifi droplets are used, as noted above, to provide nine density levels in this example. This implementation provides extraordinary color print quality in a 300 DPI ink jet printer. Other hifi droplets may be selected to achieve even greater resolution. In general, the hifi dot size and density produced by this technique will be approximately the product of the relative droplet volume times the relative dye load. A few examples illustrate the point in the following Table 4:

TABLE 4.

Examples of Hifi Droplets.			
Relative Droplet Volume	Relative Dye Load	Minimum Effective Dot Size/Density	Available Density Levels
1/4	1/2	1/8	9
1/3	1/3	1/9	10
1/8	1/2	1/16	17

The combination of reduced volume and reduced dye load may be preferable in some applications as it eases the resolution requirements as to each variable. For example, a one-fourth unit drop volume may be difficult to implement due to pen limitations. By reducing dye load in half, a one-fourth dot size may be implemented using a one-half unit droplet volume.

Other variations of number of dye concentrations, and number of print passes are possible using the methods described above. As the total number of droplets increases within a given grid location, the drop size must decrease so that the total fluid per unit area of the print media does not exceed the capacity of that media to absorb it. In systems where the total possible drops per pixel (number of passes x number of dye concentrations x number of pens), exceeds the media's capacity, driver software or system hardware can be configured to limit the allowed combinations. Thus the benefits of more levels and more saturated primary colors are made available without undue bleeding and other ill effects of saturating the paper.

FIG. 7 is a flow diagram illustrating one implementation of the invention in an ink jet printing system. Graphic image data (source data) 82, for example 24-bit RGB data, is provided by a host system or application software to a printer driver 84. Printer driver 84 includes digital halftoning software for reducing the source data to a desired resolution. The resulting print data, which may be for example 6-bit CMY or 8-bit CMYK data, or a greater number of bits reflecting the increased resolution of the invention, may be converted to form a printer control language file, conversion step 86. The printer control language file in turn is provided to a printer mechanism such as an ink jet printer 88 of the type described above.

Printer 88 may be arranged to provide one or more reduced-volume ink droplets for reduced-volume printing. In that case, data 92 indicating the available ink droplet volumes are input to the printer driver 84. Printer 88 also may be arranged to provide one or more reduced-dye loads or ink concentrations for reduced dye load printing. In that case, data 94 indicating the available dye concentrations are input to the printer driver 84. When both data 92 and 94 are provided, hifi droplets may be used. Pen layout information 98, for example in-line versus offset pen layout, is input to the driver as well. Information defining the printer and the ink cartridge(s) installed in the printer may be provided by a "print set-up" routine or the like in the host machine. Alternatively, this information may be read or sensed automatically in the printer and provided to the driver as indicated by dashed line 96. Additionally, a user or the host machine may provide an indication of a desired maximum number of dots per pixel 90 for input to the driver. A user may select a "draft mode" for example, having a small number of dots per pixel, to reduce the number of print passes, thereby trading off print quality in exchange for increased speed and reduced ink usage.

Having illustrated and described the principles of our invention in a preferred embodiment thereof, it should be readily apparent to those skilled in the art that the invention can be modified in arrangement and detail without departing from such principles. We claim all modifications coming within the spirit and scope of the accompanying claims.

Claims

1. In a non-continuous drop-on-demand ink jet printing system (10), the printing system having a predetermined printing grid (30) defining an array of pixel locations (32,34) and having a unit ink droplet volume selected for covering approximately one pixel location on a printing medium, a method of printing at a selected pixel location comprising:
   providing a print cartridge (16) having a nozzle for delivering a droplet of ink, the nozzle being located on a carriage (14) that traverses across the printing medium parallel to its surface;
   reducing the ink droplet volume so that the nozzle delivers a reduced-volume droplet of ink (48) on demand having a volume less than the unit ink drop volume; and
   depositing at least one reduced-volume droplet of ink (48) onto the printing medium at the selected pixel location, each reduced-volume droplet being deposited on a different traverse of the carriage, thereby printing the pixel with a gray scale resolution greater than the printing grid resolution.

2. A method of printing according to claim 1 wherein the reduced droplet volume is approximately 1/Nth of the unit droplet volume, where N is an integer, to allow printing any one of N+1 different volumes of ink at the selected pixel location over at most two passes of the carriage.

3. A method according to claim 1 wherein:
   the print cartridge (16) has at least three nozzles (FIG. 2), each nozzle arranged for delivering a respective one of three different color inks (CMY);
   said reducing the ink droplet volume includes providing a reduced-volume droplet on demand of each color ink; and
   said depositing step includes, on each pass of the carriage, depositing up to one reduced-volume droplet of each color ink at the selected pixel location (FIG. 4), thereby printing the pixel location with improved color resolution without modifying the printing grid.

4. A method according to claim 3 further comprising:
   increasing a black ink resolution for printing black ink at a greater number of dots per unit distance than the color resolution defined by the printing grid (30);
   reducing the black ink droplet volume in proportion to the increase in black ink printing resolution; and
   at the pixel location (32,34), printing a combination of the reduced-volume color ink droplets and the reduced-volume black ink droplets (Table 2).

5. A method according to claim 1 further comprising:
   providing first and second different ink droplet volumes on demand on the same carriage (FIGS. 3A,3B), each of the first and second volumes being less than the unit volume;
   depositing up to one first volume droplet onto the selected pixel location on the medium; and
   depositing up to one second volume droplet onto the same pixel location on the medium, thereby depositing at the pixel location a total volume of ink equal to any one of of no ink, the first volume, the second volume or the first volume plus the second volume, for printing the pixel location with four-level gray scale resolution over at most two passes of the carriage.

6. In a non-continuous drop-on-demand ink jet printing system (10), the printing system having a predetermined printing grid (30) defining an array of pixel locations (32,34) and having a unit ink droplet volume selected for covering approximately one pixel location on a printing medium, a method of printing at a selected pixel location comprising:
   defining a selected ink concentration as a standard dye load;
   selecting the unit volume and the standard dye load at respective levels adequate for forming a dot on the print medium sized to approximately cover the pixel location when a unit volume droplet of the standard dye load ink is deposited on the pixel location;

providing a droplet of ink on demand having a reduced dye load less than the standard dye load; and

depositing at least one reduced-dye load droplet of ink onto the printing medium at the selected pixel location, thereby printing the pixel with improved gray scale resolution without changing the printing grid.

7. A method according to claim 6 wherein:

the reduced volume is approximately equal to one-fourth of the unit volume; the reduced dye load is approximately equal to one-half of the standard dye load; and said depositing step includes

depositing up to a total of eight hifi droplets on the same pixel location over multiple print passes, thereby providing nine gray scale levels per pixel.

8. A printing method according to claim 6 wherein the printing system has at least three ink colors and said providing step includes providing reduced-dye load droplets on demand of each of the three different color inks.

9. A method according to claim 8 wherein the reduced-dye load for all three color inks is approximately equal to 1/Nth of the standard dye load, where N is an integer greater than 1, to allow printing any one of N+1 different amounts of dye of each color at the selected pixel location over N print passes, thereby providing (N+1) ^3 (cubed) different possible basic system colors at the selected pixel location without modifying the system printing grid.

10. A method according to claim 8 further comprising:

reducing the volume of each droplet of reduced-dye load ink to a reduced-volume less than the unit volume, thereby forming a hifi droplet; and wherein said providing step includes depositing hifi droplets of each of the three different color inks on demand to the pixel location.

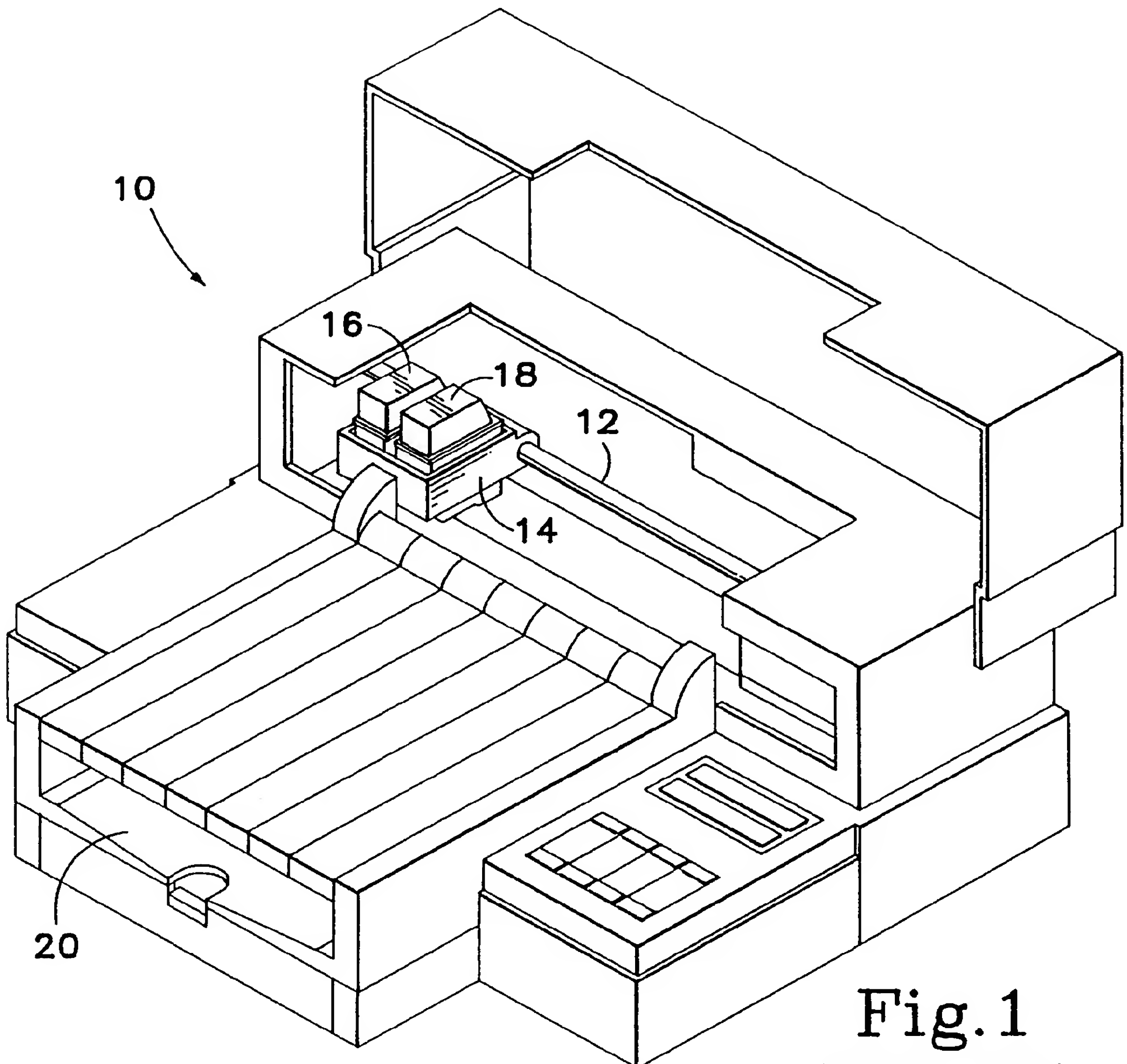

Fig.1
(PRIOR ART)

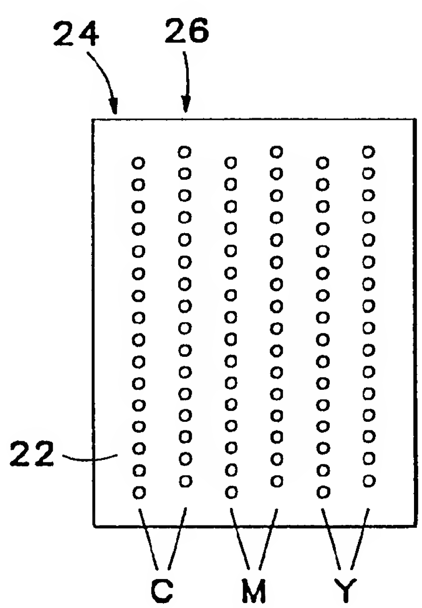

Fig.2
(PRIOR ART)

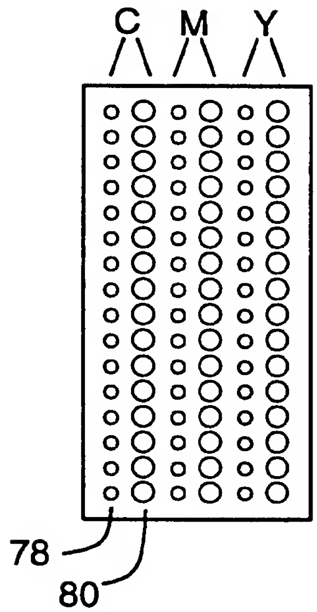

Fig. 3A

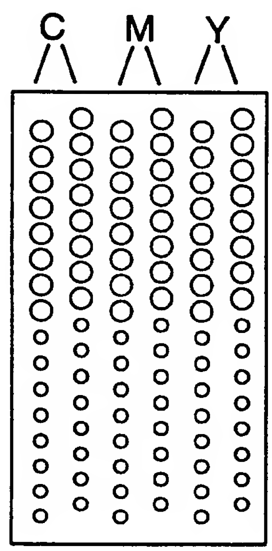

Fig. 3B

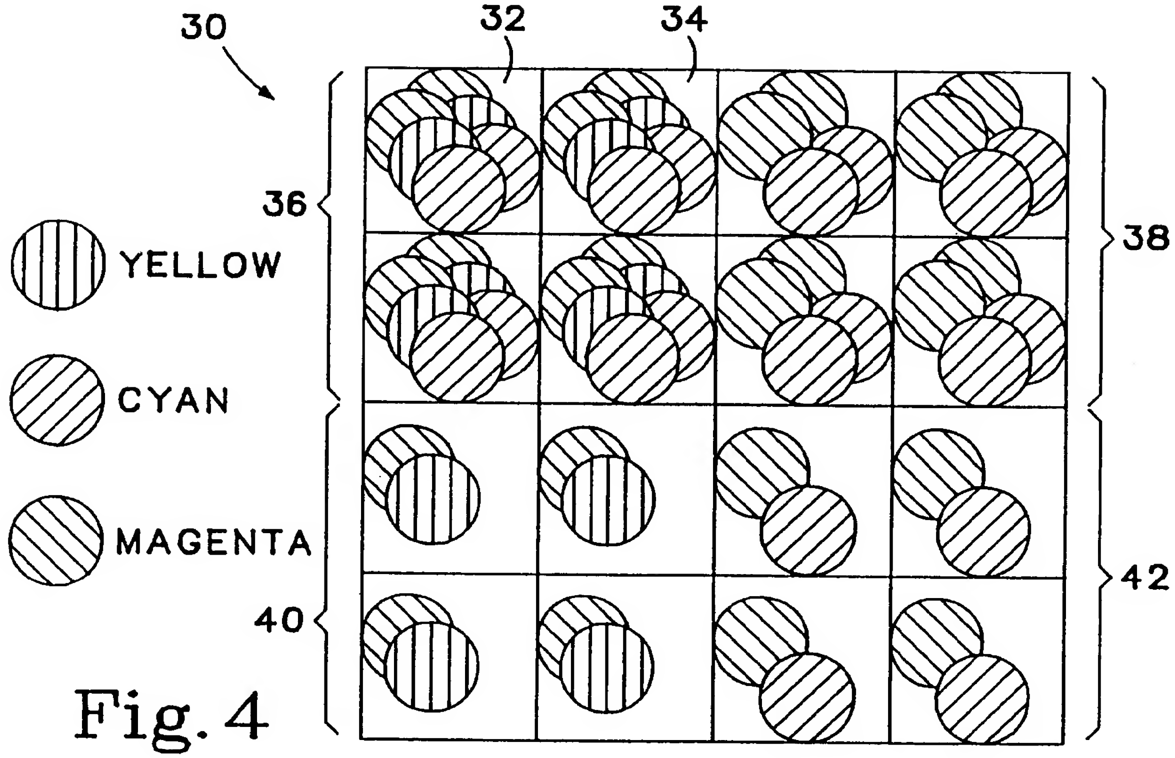

Fig. 4

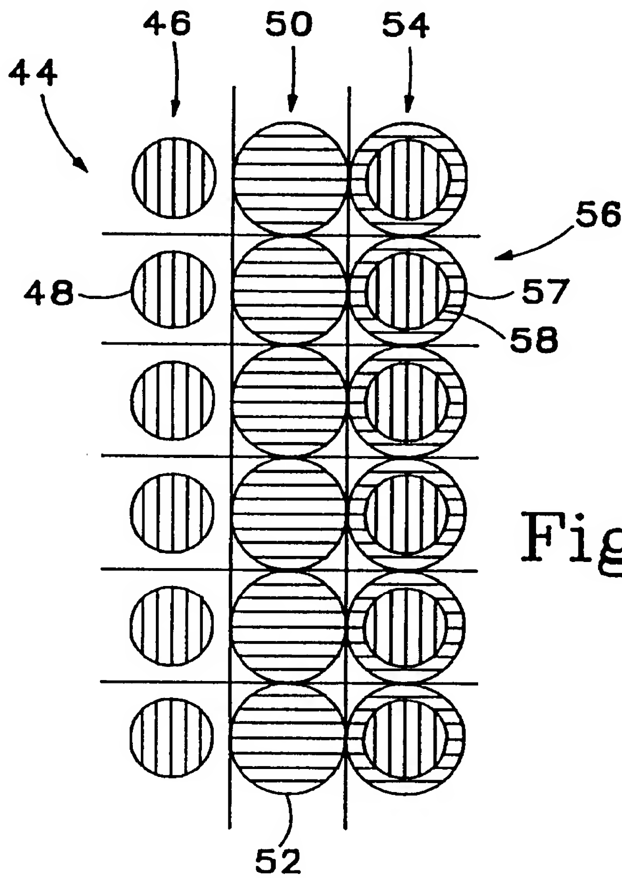

Fig. 5

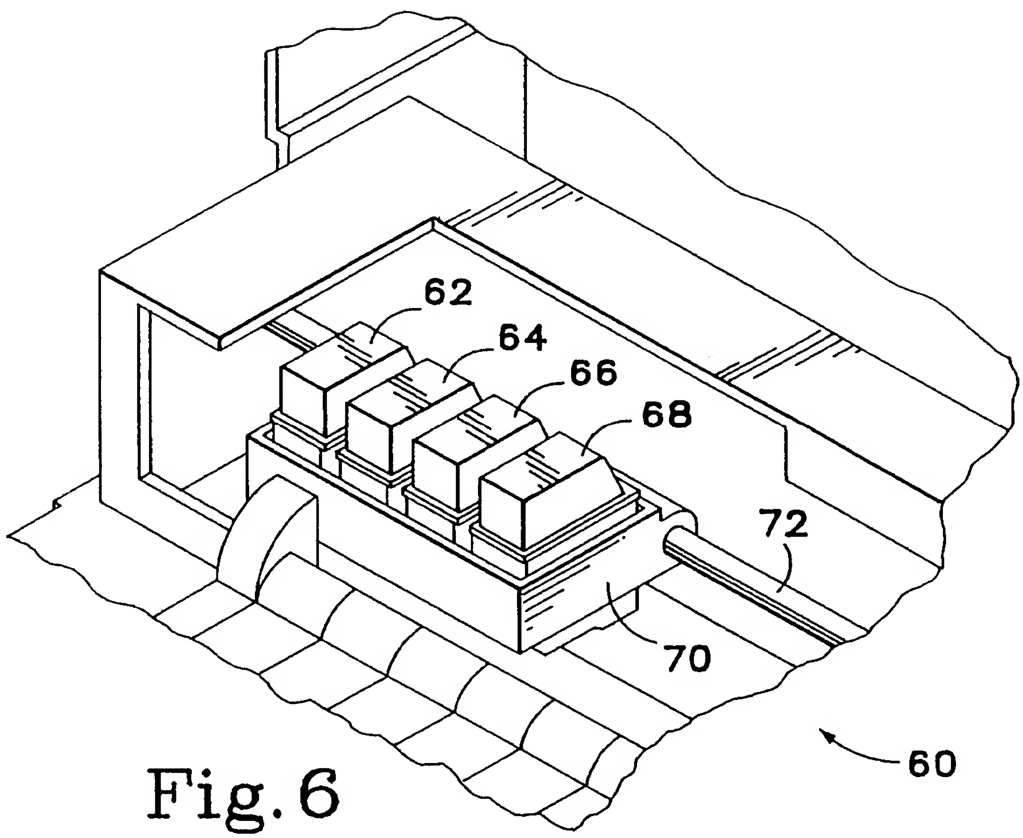

Fig. 6

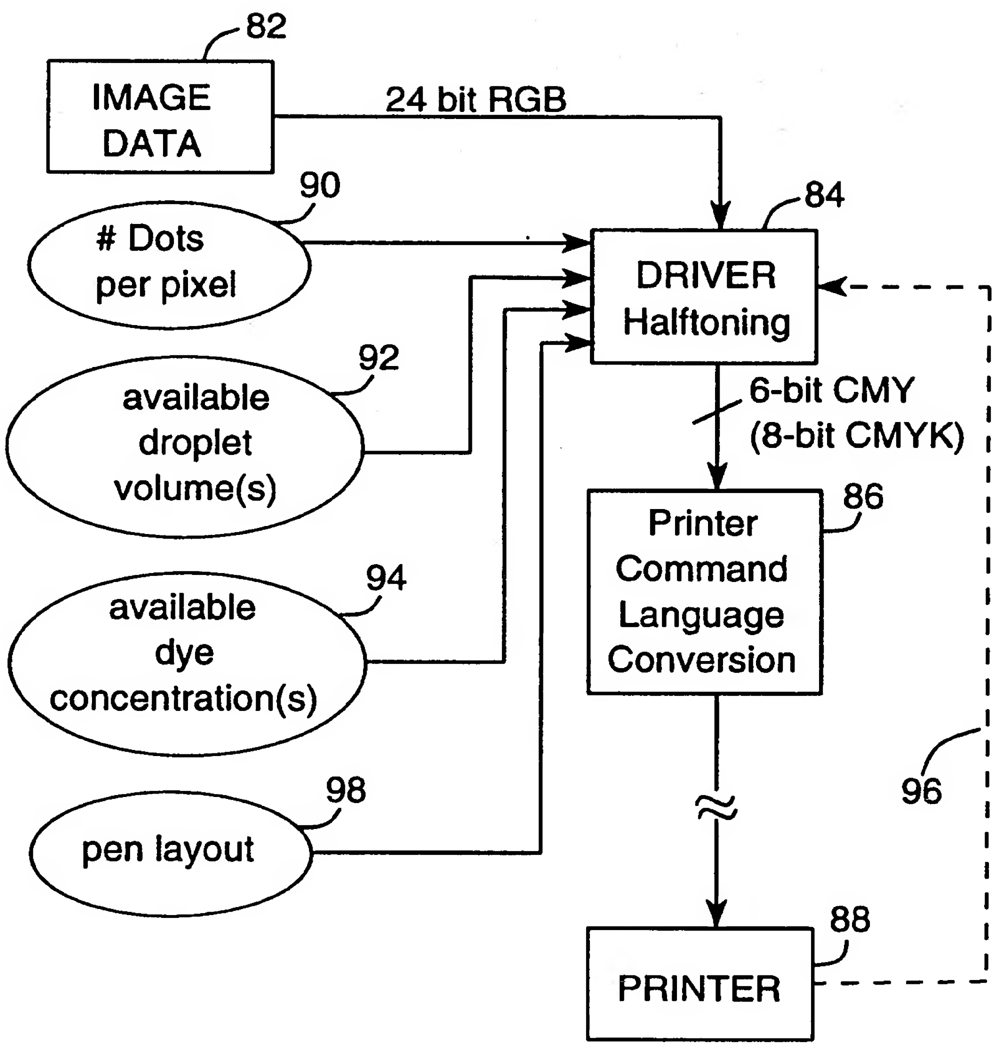
82
IMAGE DATA
24 bit RGB
90
Dots per pixel
84
DRIVER Halftoning
92
available droplet volume(s)
6-bit CMY
(8-bit CMYK)
86
Printer Command Language Conversion
94
available dye concentration(s)
96
98
pen layout
88
PRINTER

Fig. 7